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Indian Standard

IN-CORE INSTRUMENTATION FOR NEUTRON FLUENCE RATE (FLUX) MEASUREMENTS IN POWER REACTORS

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FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Nuclear Instrumentation Sectional Committee had been approved by the Electronics and Telecommunication Division Council.

In the preparation of this standard, considerable assistance has been derived from IEC Pub 568 (1977) 'In Core Instrumentation for Neutron Fluence Rate (Flux) Measurements in Power Reactors', issued by International Electrotechnical Commission (IEC).

In reporting the results of a test or analysis made in accordance with this standard, if the final value, observed or calculated, is to be rounded off, it shall be done in accordance with IS 2 : 1960 'Rules for rounding off numerical values (*revised*)'.

Indian Standard

IN-CORE INSTRUMENTATION FOR NEUTRON FLUENCE RATE (FLUX) MEASUREMENTS IN POWER REACTORS

1 SCOPE

This standard applies to in-core neutron detectors and instrumentation which is designed for safety, information of control purposes. It also applies to components in so far as these components are contained within the primary envelope of the reactor. The detector types usually used are d. c. ionization chambers, fission ion chambers and self-powered neutron detectors.

This standard is intended as a code of practice for the design of in-core instrumentation for neutron fluence rate measuremenrs in thermal neutron reactors designed for power production. The major emphasis in this guide is on the general design aspect of on-line systems.

NOTE — For the principles of overall system design and purpose of neutron flux measurements, reference should be made to IS 12930 : 1991 'General principles of nucler reactor instrumentation, Clause 2'.

2 REFERENCES

The following Indian Standards are necessary adjuncts to this standard:

IS No.	*Title*
11797 : 1985	Radiation detectors for instrumentation and protection of nuclear reactors
12930 : 1991	General principles of nuclear reactor instrumentation

3 DEFINITIONS

For the purpose of this standard, the following definitions are applicable.

3.1 Sensitivity (of a Detector)

The sensitivity of a detector to the radiation to be measured is given by:

$$S = \frac{\text{variation of the output quantity} \atop \text{(detector response)}}{\text{variation of the input quantity} \atop \text{(radiation to be measured)}}$$

In most applications, the detector is linear and has a negligible output signal for zero input.

Hence sensitivity

$$S = \frac{\text{output quantity} \atop \text{(detector response)}}{\text{input quantity} \atop \text{(radiation to be measured)}}$$

3.2 Sensitive Material (of a Neutron Detector)

The material used in certain neutron detectors, either, for example, in a lining or a filling gas, which is intended to produce directly ionizing particles from the neutrons by nuclear reaction.

3.3 Burn-up Life (of a Neutron Detector)

An estimated fluence of neutrons of a given energy distribution after which the sensitive material will be consumed to such an extent that the detector characteristics exceed the specified tolerances for a specified purpose.

3.4 Useful Life (of Neutron Detector)

Operational life, under irradiation and environmental conditions restricted within specified limits, after which the detector characteristics exceed the specified tolerances. Useful life can be expressed in incident particle fluence, number of produced pulses, etc.

3.5 In-Core Neutron Detector

A detector, fixed or movable, designed for the measurement of neutron fluence rate (flux) or neutron fluence at a defined point or in a region of a reactor core or primary envelope.

3.6 Primary Envelope

An enclosure of high integrity containing the fuel primary coolant and the moderator.

3.7 Power Density

Thermal power developed per unit volume in core of a reactor.

3.8 Off-Line Neutron Detector

A detector the output signal of which is not available for readout until the detector has been removed from the measuring position. The part subjected to neutron exposure may be in the form of a gas or fluid of defined volume or in a solid form as a wire, a set of balls, etc.

After exposure, the neutron-induced radioactivity of that part is measured at a different location by suitable means.

3.9 Neutron Detector

A detector which produces an electrical signal representative of the neutron fluence rate while it is in the measuring position.

3.10 Perturbed Neutron Fluence Rate (Flux)

Mean neutron fluence rate at a location with the neutron detector placed in the same position for measurement. This quantity is equal to the detector output divided by its true (unperturbed) sensitivity and is practically equal to the neutron fluence rate averaged over the detector surface.

3.11 Unperturbed Neutron Fluence Rate (Flux)

4 GENERAL CONSIDERATIONS

4.1 In a power reactor with a core which has large physical dimensions it may be important, for operational reasons, to monitor not only the mean value of the in-core neutron fluence rate (flux) over the whole reactor core but also its spatial distribution. Local measurements at a particular position in the core are often combined with local control functions, the purpose of which is to ensure adequate safety margins for protection system parameters or to provide for optimum utilization of the fuel. Depending on the reactor type, this may be performed on a relative or an absolute basis.

4.2 Measurements of local in-core neutron fluence rate (flux) are in some cases necessary for safety reasons — for example, for protecting the fuel from damage caused by local disturbances in the coolant flow or by transients in the local power density. Such abnormal conditions may not be identified with sufficient sensitivity by means of measurements outside the core. In this case, the in-core measuring assemblies are usually connected to the reactor protection system.

4.3 In-core neutron fluence rate (flux) instrumentation may also be used to provide information of a more general nature about the reactor or about component performance. Examples of information derived from neutron fluence rate data are vibration of in-core components, boiling phenomena in a liquid coolant, total neutron fluence on individual fuel assemblies, etc.

4.4 In some reactors, neutron fluence rate (flux) instrumentation outside the primary envelope cannot be used for start-up and intermediate power operations. Measurement and control of gross reactor power and local power conditions may therefore be provided over part or all of the required range by means of in-core neutron detectors.

4.5 Special in-core instrumentation may be needed to facilitate periodic recalibration of the neutron fluence rate (flux) instrumentation described in **4.1** to **4.4** above. Both isotopic activation techniques and movable in-core detectors may be used for this purpose.

4.6 Parts of the in-core instrumentation system may be located in very severe environments. Exposure to high neutron and gamma radiations is liable to cause transformations and structural changes in the materials used and to affect the mechanical and electrical properties of the equipment. Great care shall, therefore, be taken in the choice of suitable materials. Furthermore, design consideration shall, in most cases, be given to the effects of high environmental pressure, pressure cycling, high temperature, temperature gradients and temperature cycling.

4.7 Those parts of the instrumentation system which are installed within the primary envelope of the reactor are usually inaccessible for maintenance or replacement for long periods of time. It is, therefore, often necessary to provide for adequate system availability by means of redundancy. Detectors may be spatially distributed such that adequate coverage is ensured for a specified acceptable number of failure.

5 SYSTEM DESIGN

5.1 General Requirements

5.1.1 The possible influence of instrumentation intended for in-core installation on the operating characteristics of the reactor shall be carefully evaluated. In particular, this evaluation shall consider maximum reactivity transients which may be caused by conceivable malfunctioning of the equipment, possible disturbance of the coolant flow in normal and abnormal conditions, any risk that the equipment will disturb the performance of safety actions and the risk of malfunctions which may cause damage to the primary envelope integrity.

The analysis should take account of procedures for replacement of in-core equipments. The procedure which best ensures plant availability should be preferred and it shall not degrade the specific safety requirements. The provision of spare parts or the ability to change the detector with the reactor at power should be considered.

5.1.2 In cases where in-core instrumentation is used for reactor protection action or is otherwise necessary for safe operation of the reactor, it shall be designed in accordance with the protection sysytem requirements (under consideration) of IS 12930 : 1991.

5.1.3 The in-core parts of the system should contain, as far as possible, only materials which have known acceptable properties in the ambient conditions prevailing in the reactor core. In particular, the influence on pertinent characteristics of long term neutron and gamma irradiations and temperature cycling should be known, preferably from prototype tests or from interpretation of experimentally obtained data.

5.1.4 The consequences of equipment failure to the reactor should be taken into account in the choice of in-core components as well as the design of primary envelope penetrations. For example, the insulation materials of in-core cables should not react adversely with the surroundings if the cable sheath is broken.

5.1.5 The instrumentation system should be designed to facilitate the functional testing, if required, of the in-core components during reactor operation.

5.1.6 For instrumentation systems intended for power distribution measurements, it is necessary to know from theoretical calculations the relationship between the power density and the signal produced by the neutron detector in different parts of the core for all normal reactor conditions throughout the fuel cycle. Since different detector types may have different neutron spectral responses, this relationship will influence the choice of a suitable detector type and the accuracy with which the power distribution can be measured.

5.1.7 The sensitivity of every neutron detector used in a power distribution measuring system should be known relative to a reference throughout its operational life. This means that recalibration should be possible during operation or that the detector calibration should be largely independent of the irradiation up to very high neutron fluence or that the burn-up effect on the detector sensitivity can be calculated. The above work should be done with an accuracy (typically about ± 3 percent relative to the reference sensitivity) and at time intervals consistent with the system requirements as a whole.

5.1.8 Neutron measuring systems used for gross power control or safety shall have adequately short response times. Response times for the measurement assembly of about one-fifth of a second are typical. Measuring assemblies used only for manual control or a power distribution may have a slower response.

5.1.9 For on-line detectors, the signal usually contains back-ground components originating from different sources — for example, gamma radiation from the reactor fuel or radiation from induced radioactivity in the core structure or in the detector itself. Part of this background signal is not proportional to reactor power is considerably delayed with regard to the neutron fluence rate. It is recommended that the relative back-ground content in the detector signal, if significant, should be known for different reactor operating conditions. End-of-life ratios of signal-to-total background in the order of 5 : 1 may apply to measuring assemblies used at full power.

5.1.10 The useful life of an in-core detector assembly, being a function of detector characteristics as well as of assembly design and choice of associated electronic components, should be in excess of the period between scheduled reactor maintenance shut-downs.

5.1.11 The system should be designed such that radiation leakage or beams do not make maintenance unduly difficult.

6 IN-CORE NEUTRON DETECTORS

6.1 General Requirements

6.1.1 Different types of on-line detectors are used to meet different reactor operating requirements. At low and intermediate powers, the detector may be operated in the pulse counting or variance mode in order to improve gamma background discrimination whereas d.c. mode operation is usually used in the high power range. Detector types usually used are d.c. ionization chambers, fission ion chambers and self-powered detectors.

6.1.2 In-core detectors should be of such dimensions that the fluence rate distribution and the coolant flow conditions in the core are not significantly disturbed.

6.1.3 The creation of long-lived gamma and/or beta activity in an in-core detector through neutron activation will usually develop background effects in the detector signal as well as radiation protection problems during handling procedures. These effects should be carefully considered and minimized as far as possible through proper choice of structural materials as well as the mechanical design of the detector. Similar consideration should be given to mechanisms, etc, which will be used during maintenance.

6.1.4 The absorption of radiation by the detector when it is operated at high power levels may lead to substantial production of heat. This effect shall be considered in the detector design as well as in its installation. If this effect is expected to result in a detector temperature appreciably above the ambient temperature, this should be taken into account.

6.1.5 In-core detectors intended for use at low reactor power may be installed in such a way that they can be withdrawn from the core during high power operation. By this means, the effects described in **6.1.3** and **6.1.4** are minimized and an adequately useful detector life obtained.

6.1.6 For detailed neutron fluence rate distribution measurements at high power levels, one or more movable in-core detector probes may be used. Each probe may be moved inside the core to obtain power density distribution within suitable time intervals. Since the detector is exposed to intense neutron irradiation for only short periods, the sensitivity change due to burn-up of sensitive material can be kept very low. This technique is also used for recalibration of permanently installed in-core detectors during reactor operation.

6.1.7 Cables and connectors, in so far as they are integral parts of the in-core detector, should meet the requirements stated in **6.1.2**, **6.1.3** and **6.1.4** above and their performance in in-core operating conditions should be specified by the detector manufacturer.

6.2 Mechanical Characteristics

6.2.1 The following mechanical characteristics of in-core neutron detectors and their integral components shall be specified in writing by the manufacturer with appropriate units:

a) An outline diagram, with tolerances, giving detector dimensions, the sensitive length and the position of the sensitive volume.

b) In-core detector cable, outside dimensions, sheath thickness and conductor thickness together with bending data (numbers of bends and radii, etc) relevant to the proposed applications.

c) Main materials in the detector structure, cable and cable termination including soldering or brazing materials.

d) Major impurity elements in the materials according to (c) above in particular elements which may cause excessive parasitic detector signals, post-irradiation activity in the detector body or thermal neutron absorption.

e) Sensitive material of the detector with regard to nominal chemical composition and total quantity.

f) Pressure and main constituents of filling gas, if any.

g) Resistance to shock and vibration.

6.3 Electrical and Nuclear Characteristics

6.3.1 The following electrical and nuclear characteristics, where applicable, shall be specified in writing by the manufacturerer with appropriate units:

a) Mode (or modes) of operation.

b) Polarization voltage, recommended operating range and maximum permissible value.

c) Discriminator bias plateau characteristics.

d) Saturation characteristics.

e) Average value of electric charge delivered at the output per neutron captured.

f) Charge collection time.

g) Sensitivity of the detector for the proposed mode or modes of operation to neutrons of stated energy distribution (on a perturbed basis), at 25°C and at the maximum operating temperature. The precise form of this energy distribution can be of importance to the user and may be the subject of consultation.

h) Sensitivity of the detector to gamma radiation or the influence of gamma radiation for the proposed mode or modes of operation under stated conditions (for example typical in-core gamma spectrum or Co 60 spectrum).

j) Sensitivity (electrical signal) of the in-core detector cable per unit length to neutrons and gamma radiation under the same conditions as in (g) and (h) above.

k) The range over which the detector follows its calibration characteristics within stated limits.

m) Residual current characteristics of the detector and cable separately, after long-term neutron exposure.

n) Maximum variation of the neutron sensitivity per unit length of the detector along its sensivity length, where meaningful.

p) Electrical insulation leakage current of the detector itself at specified voltage(s) between electrodes, electrodes to case, and electrodes to shield (if used):

- at 25°C and no radiation field.
- at miximum operating temperature and no radiation field.

q) Electrical insulation leakage current of the cable (in the case where it is an integral part of the detector) at specified voltage(s) between individual conductors and between the signal conductor and cable sheath (with all other conductors connected to the sheath) if applicable. The specification shall be given for the same ambient conditions as in (p) above.

r) Electrical capacitance to the case at the output from the signal electrode.

6.4 Range of Operating Conditions

6.4.1 The following operational limits, where applicable, shall be specified in writing by the manufacturer, with appropriate units for the detector as well as for the cable and cable termination:

a) Maximum ambient temperature for continuous operation.

b) Maximum permissible temperature.

c) Limiting transient temperatures.

d) Maximum neutron fluence rate.

e) Maximum gamma fluence rate, if necessary.

f) Maximum gamma fluence.

g) Burn-up life (for the detector).

h) Maximum operating ambient pressure.

j) Useful life.

6.5 Prototype Testing

6.5.1 Prototype testing of in-core neutron detectors and cables should take into account all the characteristics listed in **6.2** and **6.3** and, where relevant, **6.4**. Emphasis should be given to performance characteristics relevant to long-term operation under in-core conditions. The tests should, as far as practicable, be made to demonstrate long-term stability of mechanical and electrical characteristics, for example, detector gas pressure and composition, electrical insulation and electrical interference rejection. Moreover, these tests should consider back ground signal build-up, gamma heating effects and sensitivity changes due to burn-up or filling gas deterioration. Tests under in-core ambient conditions, including pressure and temperature cycling, should be performed to such an extent that it is demonstrated whether detector design can be expected to meet the requirements in a power reactor application with regard to the probability of failure.

Units which utilize moveable detectors usually include driving systems to be installed outside the reactor core. Prototype tests should take into account not only the performance of the in-core parts but also possible failure modes of the driving system. This system and its control and position readout should be demonstrated to be capable to positioning the detectors to the accuracy required for the intended function. Special attention should be given to effects of temperature gradients on the detector and its guides, effects of pressure cycling and of wear on moving parts.

6.6 Production Testing

6.6.1 In-core neutron detectors and detector assemblies shall undergo final production tests designed to ensure conformity of manufacture (Detailed test methods, as applicable, are given in IS 11797 : 1985. For in-core applications the following characteristics should be particularly considered:

a) Mechanical resistance to vibration and shock (microphonic tests or other tests corresponding to the operational environmental conditions).

b) Cable sheath and detector evelope integrity (helium gas, steam or hydrostatic test).

c) Quality of welding or brazing, where this is important for reliable operation (radiography).

d) Insulation resistance measured at output terminals at specified out-of-core conditions, both at 25°C and maximum operating temperature.

e) Saturation characteristics or discriminator bias plateau characteristics, where applicable. This may be done on a valid statistical sampling basis for large production lots where traceability of detector elements exists.

f) Electrical insulation quality.

g) Thermal neutron sensitivity sampling techniques of item (e) may apply.

h) Gamma sensitivity Co 60 or spent-fuel spectrum. Sampling techniques of (e) above may apply.

NOTE — With in-core detectors of current design it is usually possible to perform tests according to (e) and (g) above in such low radiation fields that the activation effect is kept below limits acceptable for handling and transportation. Should this not be the case, the testing may be applied to batch samples which are not intended for delivery.

7 TESTING OF SYSTEM BEFORE ORERATION

7.1 The mechanical integrity of the in-core equipment after installation shall be checked according to a general pre-operational testing programme prescribed for all parts inside the primary envelope.

7.2 The programme for electrical tests on the installed in-core detector assemblies should be designed to reveal any fault caused during installation. It may include insulation tests at normal temperature and measurement of electrical interference in the detector signal under simulated operating conditions. As far as practicable, the correct response of the neutron detectors should be checked by means of neutron sources.

7.3 Performance tests of the whole in-core neutron fluence rate (flux) instrumentation system should be comprehensive and include mechanical and electrical components. They should take into account the influence of external electrical interference and mechanical vibrations, positional system accuracy and the settings of all system parameters such as discriminator thresholds, alarm levels, signal amplifier gains, etc.

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